About Birds, Sex – and why Failure is good for Business and Petroleum Exploration

by

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ABSTRACT: In this text, we will explain how biological systems and businesses are similar in the way they behave and evolve. We will then argue that a good measure of fuzziness, serendipity, uncertainty is beneficial for biological evolution and business. We will then discuss why serendipity (explained below) is an integral part of evolution. We will try to demonstrate that the same rules that make biological evolution successful apply to business, too. Mathematical concepts and their limitations will be discussed briefly. A short example of how this applies for petroleum exploration has been added.

Keywords: *evolution, serendipity, evolutionary suicide, oi&gas exploration.*

1.0 What is Serendipity and why is it important?

Serendipity[1] is the "phenomenon of finding valuable things not sought for". Because this word is pivotal to the argumentation of this text, let us define what serendipity is and how it is used in the context of this paper:

- The occurrence and development of events by chance in a happy or beneficial way. Synonyms are: chance, happy chance, accident, happy accident, fluke.
- An unsought, unintended, and/or unexpected, but fortunate, discovery and/or learning experience that happens by accident.
- A combination of events which are not individually beneficial but occurring together to produce a positive outcome.
- Serendipity is sometimes used loosely as a synonym for luck; more careful usage, particularly in science, emphasizes specifically "finding something when looking for something else, thanks to an observant mind." In this paper, we will enlarge the scope of the definition to include all possible outcomes.
- Coincidence – an unanticipated action with a negative or positive outcome that can be
  - Happenstance – an unanticipated circumstance with a positive outcome, or
  - Mishap – an unanticipated action with a negative outcome.

2.0 The Objective of Life

The objective of every living organism is the procreation of its species. Life tries to achieve this by striving for the survival of the individual in conjunction with the survival of the species, whereby the survival of the individual is subordinate to the survival of the species. This is because an individual has a limited life time (anyway) and can be sacrificed for the greater good of the species (think of bee hives or ant societies). Food (substance that can be metabolized by an organism to give energy and build tissue) supports the survival of the individual whereas sex for procreation supports the survival of the species[2]. Therefore, the relative success of evolution can be gauged by reproductive success which is a line of thought that has also been put forward already by Spencer in 1864.

2.1 Biological Evolution

The mechanism of biological evolution was originally researched by Alfred Russel Wallace (Wallace, 1855) and others and eventually published by Charles Darwin (Darwin, 1859) based on his own works and correspondence with Wallace.

Biological evolution uses mechanisms such as reproduction, mutation, recombination, and selection. Evolution is a process of trial and error (discussed below, also Wright, 1932) and does not seek one particular or optimal solution as it is not a directed process. It is simply the procedure whereby advantageous genes are favored in a given environment, and less advantageous ones are not favored. In evolution, the current environment acts as a filter which favors a certain modification or rejects it. Those individuals who are best able to adapt survive to reproduce while those who cannot don't or will eventually become extinct. The byproduct of this sort of natural selection is evolution, as the selected-for genes are passed on to subsequent generations until the vast majority of the population carries those advantageous genes. Evolution of the

1 The word was coined by Horace Walpole in 1754. In a letter he wrote to a friend, Walpole explained an unexpected discovery he had made by reference to a Persian fairy tale, The Three Princes of Serendip. For the etymology see Goodman, 1961.

2 Malthus, 1798, one of the first thinkers who posited the population theory wrote: "First, men and women cannot exist without food. Second, the passion between the sexes drives them to reproduce."

population then takes place after the repeated application of reproduction, mutation, recombination and selection.

The fitness for survival in biology (or the payoff in business) determines the quality of the solution. Fitness – or the successful adaption to the environment – can be thought of as a fitness landscape. This landscape can be visualized as a surface in three dimensions, but is not necessarily restricted to only three dimensions. As there can be several maxima (peaks, mountains, valleys) in this surface, it follows that there is no single best outcome of the evolutionary process. In fact, there can be two or more “good” solutions which might mean “good enough” or second-best as will be discussed later in this paper. To make things more complicated, the fitness landscape varies with time, i.e. the current best solution(s) may not be the best for the future environment.

In short, evolution is actually a trial and error or a shot-gun approach to an unknown future with the expectation that at least one of the outcomes will be fit and suitable for the future. As the number of evolutionary permutations is finite and the future is utterly unknown, some lineages may become extinct resulting in an evolutionary failure. However, in a wider picture, these extinct lineages make space for other populations, other phylogeny groups. Considering, that the living space is also limited, the extinction of one or a few lineages is not necessarily a disadvantage for the entire living matter because it will make room for other groups.

2.1.1 Darwin’s Axiom

Charles Darwin once wrote: **“It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change.”** In other words, evolving systems (species, business models) that are not responsive to change are doomed and will become extinct. As far as science can see today, this axiomatic statement holds true.

Why is this important? – We can safely assume that it is impossible to guess or even know what the future will be like. All attempts to foresee the future are either amiss – and sometimes even very wrong – or simply fortuitous guesses. If it was possible to predict the future, it would be very easy to prepare for it. However, as the future is utterly unknown, it is important to have options at hand to chose from. In the case of biologic evolution these options are provided by mutants, some of which will be adapted to the new environment and assure the survival of the species for the next generations while other mutants will fail and die which is the cost of evolution.

2.1.2 The Struggle for Survival

The concept of the struggle for existence and survival concerns the competition for resources needed to live and leads to the concept of the “survival of the fittest[3].” Struggle for existence does not only occur in biology but also can refer to human society, or to organisms in nature or entire systems. The concept of competition and fight for space and resources in evolutionary biology applies also nicely to competing businesses, the struggle for existence between competing ideas (within the minds of people engaged in intellectual discussion, e.g. communism vs capitalism), (Huxley, 1880), related organized systems (societies, countries) or technical standards (eg. metric vs imperial measurement units, Windows vs. Linux and many more examples).

2.1.3 Evolutionary Suicide or Paradise

The analogy of species’ extinction to bankruptcy or even hostile take-over in business is obvious. It is an interesting fact that just a few selfish individuals can cause mayhem and lead to the extinction of an entire population. Such selfish individuals may thrive at the expense of altruistic individuals in a group – making them the “fittest” – even though they make the group as a whole less competitive. Such cheaters can have disastrous consequences. Haldane (1932) suggested this could even lead to the extinction of populations – a phenomenon called evolutionary suicide. Experimental evidence and models suggest he was right (Parvinen and Diekmann, 2013). The similarity of Haldane’s model to the present-day capitalistic social-Darwinism[4] are striking.

On the other hand, instead of using a rule that is based on the survival of the fittest *individuals*, what if we consider an alternative approach whereby we add all fitness values of the entire population together, and optimize for this resulting sum instead of maximizing the well-being of a single lineage over successive generations? In short, what if we would consider the fitness of an entire population as a whole as a measure for the probability of its survival. Would we – in society – be creating a Marxist utopia?

3.0 Common Problems – Examples

To illustrate the complexities involved in how the struggle for survival may be quantified so that optimum levels of energy expenditure and resource gathering may be reached, two commonly discussed opti-

3 “Survival of the fittest”: is a phrase that originated from Darwinian evolutionary theory as a way of describing the mechanism of natural selection. Spencer, 1864, first used the phrase, after reading Darwin, 1859. Spencer (ibid.) draws parallels between his own economic theories and Darwin's biological ones.

4 It has been claimed that the-survival-of-the-fittest-theory in biology was interpreted by late 19th century capitalists as “an ethical precept that sanctioned cut-throat economic competition” and led to the advent of the theory of social Darwinism which was used to justify *laissez-faire*-economics, war and even racism. However, these ideas predate and generally contradict Darwin's ideas. In fact, the term “social Darwinism” referring to capitalist ideologies that was introduced by Hofstadter in 1944 is actually completely misleading.

mization problems – one occurring in nature and the other in business – that should be examined. These are the problems of the bird seeking food and those of the traveling salesman.

3.1 The Bird Seeking Food

Let's think of a bird in the month of June flying though an apple orchard to feed on worms which occur as parasites on apple trees. These worms are the primary source of food for this species of bird. The bird has found an orchard and begins to feed on the worms it finds on the first tree that he visits. But the food on this tree is sparse and will not be enough. Therefore, he flies to another tree to find out if there is richer food to be found there. If so, he will choose to remain on the new food-rich tree until he is full or the supply of worms is eaten up. If not, he has the option of returning to the first tree and continuing to feed on the mediocre supply there – at least something – or he could explore other trees.

The hungry bird faces the following dilemma:

- If he stays on the first tree, where there is only little food, he might miss another tree which has much more to offer and that may even be close by.
- Or the bird may choose to fly from tree to tree to find the best food source in the current orchard or he may even choose to fly much farther to another orchard in order to find a more abundant source of worms. If he does this, he uses up precious energy without having enough time to feed and runs the risk of remaining hungry and facing starvation.
- In a simplified way, the trees in this orchard can be thought of as maxima or peaks in a fitness landscape.

The solution to the bird's dilemma is clearly to find the right balance between feeding and searching for other sources. But exactly *how much* searching and how much flying would be best is what constitutes this tricky optimization problem. Obviously, this depends on a number of parameters such as the distance between trees, the energy required to fly from one tree to another, how many worms (nutrients, energy) per tree or per kilometer flown need to be known. But even then, this apparently simple optimization problem with a single bird does not have an exact mathematical solution.

Furthermore, introducing group of birds which may be searching for food in the same orchard complicates the problem even more. By feeding on a particular tree, the birds would signal to the other individuals where there is food. Other birds would come to the same tree and by doing so amplify the "here-is-food"-signal to the others. Eventually, there would be fierce competition for the resource. There are also aspects of cooperation and the concept of group wisdom (Galton, 1907) where the individuals of a group try to find a single solution to a common problem which would complicate matters even more.

3.2 The Traveling Salesman Problem

Related to business, another simple optimization problem which is not much different from the bird seeking food is the traveling-salesman-problem (TSP) which has been posited since the 19th century. It goes like this; imagine a salesman traveling though his area with the objective of making a number of business calls to potential customers. The problem that he faces is that he wants to spend as little time on the road and keep the total distance he travels down in order to minimize the time, cost and effort spent on the road.

This particular optimization problem, due to its important implications, was first considered mathematically in the 1930s to solve a school bus routing problem. It turned out, that this – initially simple – problem does not have an exact mathematical solution. Permutations of this salesman-problem include crane scheduling in a port container terminal, computer wiring (Matai et al., 2010), as well as programming the drilling of holes into a printed circuit board and even planning the drilling of a series oil wells that will minimize the cost and time of a rig move.

3.3 The do-nothing Case

The two examples have been included to illustrate that the do-nothing option cannot be a solution; it would obviously not lead to a useful outcome. Much to the contrary, any activity, even aimless and undirected action ("serendipity") will be better than inactivity.

An old Chinese proverb says: "If we do not change direction, we are likely to end up where we are headed." Such a linear process may not be the best course of action in many situations.

4.0 Various Approaches and Solutions

4.1 Mathematical Model Approaches of Evolution

Serendipity, in the parlance of this paper, is treated in artificial-intelligence-mathematics with evolutionary algorithms (EA) which is a subset of evolutionary computation, a generic population-based metaheuristic[5] optimization algorithm. An EA uses mechanisms

5 In computer science and mathematical optimization, a *metaheuristic* (MH) is a higher-level procedure or heuristic designed to find, generate, or select a heuristic (a partial search algorithm) that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited computation capacity. MH sample a set of solutions which is too large to be completely sampled. MH may make few assumptions about the optimization problem being solved, and so the results may be usable for a variety of problems. Compared to optimization algorithms and iterative methods, MH does not guarantee that a globally optimal solution can be found in certain problem classes.

which are inspired by biological evolution. In most real applications of EAs, computational complexity is a prohibiting factor.

A central premise of the theory of evolution through natural selection is that when beneficial mutations appear, they should spread throughout a population but this outcome is not at all guaranteed. Random accidents, illnesses and other misfortunes can easily erase mutations when they are new and rare – and it is statistically likely that they often will. Mutations should theoretically face better odds of survival in some situations rather than others. A mutation might get permanently lost in the crowd unless its advantage is great. Yet, if a few individuals regularly migrate to their own region or island to breed, then a modestly helpful mutation might have a better chance of establishing a foothold and spreading back to the main population. Then again, it might not so that the outcome would depend entirely on the precise details of the scenario. Biologists study these population structures to understand how genes flow. Lieberman et al (2005) applied the methods of graph theory to model evolution. With these methods, they could demonstrate that certain population structures (dubbed as bursts, stars, hubs, self-loops) can suppress or enhance the effects of natural selection.

Without going into detail of the intricate mathematical approaches, it can be summarized that mathematics and computer simulations cannot yet completely replicate the processes of biological evolution.

4.2 Trial, Learning and Adaptation

Another manifestation of serendipity is trial and error (T&E)[6] which is a method of problem-solving or solution-seeking characterized by repeated, varied attempts which are continued while the degree of success is observed. The purpose of T&E can be either structured, by varying parameters to obtain knowledge of the underlying processes or a entirely random to seek a solution. Oftentimes the solution-seeking trials are discontinued once a satisfying solution – not necessarily the best solution, often a second-best option – has been found.

4.3 The Theory of Second-Best

The theory of the second best concerns the situation when conditions of a model cannot be satisfied. The economists Lipsey and Lancaster (1956) showed that if one optimal condition cannot be satisfied, it is possible that the next-best solution could be sufficient. It may involve changing other variables of the model. This idea is derived from the equilibrium theory[7] in the world of economics. In social science, the difference between optimal and second-best has come to stand generally for the gap between individual rationality and group rationality, the latter broadly related to group wisdom (Galton, 1907).

How about second-best in evolution? – We are of the opinion that there cannot be a best or second best at the time the mutations occur because it is utterly uncertain which environmental requirements will prevail in the future and which traits will therefore become successful. Only the evolutionary success of a given strain or lineage at a later time will be a measure for the success of a genetic variation. This leads us to looking at reproduction.

5.0 Applications

5.1 Sex

Sex is good – also for evolution. We know from paleontology that the living creatures, plants and animals, initially reproduced asexually by means of fission, vegetative reproduction, spores, etc. An asexually reproducing population can grow rapidly with each generation. Sexual reproduction, on the other hand, came about one billion years ago and was an immediate success. The origin of Eukaryotes (organisms whose cells have a nucleus enclosed within membranes) and – later – higher evolved organisms may have been driven by the advent of sex.

5.1.1 The Cost of Sex

From that time onward, which is over most of the geological time, the preferred course of evolution was sexual reproduction, although – at first glance – this method comes at a cost: Half of the species' population – the males – appear useless and are only needed for reproduction. For any sexually reproducing species, there is a two-fold cost: only half the species' individuals can bear young, and males must go through the – often complicated procedures – to find suitable females. For the sake of completeness, we have to mention here that some plants and animals can and do reproduce asexually or even can choose from the both options. However, the preferred method always remains the sexual procedure. (The mathematics of sexual reproduction were described by Smith and Smith, 1978, and the importance of "biparental reproduction" was summarized by East, 1918).

5.1.2 The Advantages of Sex

Obviously, sexual reproduction offers significant advantages to a species because despite the two-fold cost of sex, it dominates among many forms of life, implying that the fitness of offspring produced outweighs the costs. With sexual reproduction, there are

6 *Trial and error* is also referred to as *guess and check* or *generate and test* in other fields of science.

7 Equilibrium theory attempts to explain the behavior of supply, demand, and prices in a whole economy with several or many interacting markets, by seeking to prove that the interaction of demand and supply will result in an overall general equilibrium. General equilibrium theory (Walras, 1874) contrasts to the theory of partial equilibrium, which only analyzes single markets.

two copies of every gene, which minimizes the expression of harmful mutations. Sexual reproduction derives from recombination, where parent genotypes are reorganized and shared with the offspring. This stands in contrast to single-parent asexual replication, where the offspring is practically identical to the parent, only minor genetic variations occur whereas genetic variation seems to be the purpose of sexual reproduction.

Genetic variation, protection from major and catastrophic mutations, an increased resistance to parasites and viruses and disease-causing pathogens, which coevolve with their hosts, changing rapidly between generations appear to be the main driver. Sex helps to fight this constant bombardment through increasing genetic variation, and helps to spread favorable traits quickly. Other advantages are the removal of deleterious genes and the production of novel genotypes.

Overall, sexual reproduction introduces more genetic variations which can be considered serendipitous as it suppresses the evolution of those genes which are harmful for the species. Although sex comes at a significant cost (slower procreation, higher consumption of resources such as food, living space, etc.), the advantages of having more options to choose from and/or to compete against on the basis of fitness for their environment greatly increases the chances of survival and outweigh the disadvantages so that the dominant and preferred method of reproduction of nearly all higher lifeforms is sexually.

5.2 Serendipity in Business

Serendipity in business is often mocked as beating about the bush, or lacking focus, because there is no scientific hypothesis to be tested or business model to be followed, and thus the possible outcomes of such serendipitous exercises are unknown – this is why serendipity is frowned upon by business people, and not accepted as a scientific method. Marcel Duchamp, a chess player and artist of the last century, held the position that “where there is no [defined] problem, there cannot be a solution.”

Much to the contrary, a suitable problem for an existing solution may come later. For example, when the Laser light was invented by Theodore Maiman in 1960 (Maiman, 2018), it was mocked as “a solution in search of a problem[8].” Today, Laser beams are applied to measure the distance to the moon or illuminate tissue in two-photon microscopy (Denk et al., 1990) as well as in a plethora of other applications.

Moreover, a similar sequence of events can be seen in the evolution of *mammalia*. Precursors of this vertebrate group already existed as early as the Carboniferous period and were established and diversified in the Jurassic. However, it was only after the Cretaceous–Paleogene extinction event, which wiped out the dinosaurs, that the placental and marsupial mammals diversified throughout the Paleogene and Neogene periods to take on new forms and fill the ecological spaces which were previously occupied by competing species. Albeit very simplified, this can serve as another example of second-best taking over or a preexisting solution finding its place.

By negating the potential benefits of serendipity, we succumb to the illusion that everything can be known and predicted, and that everything unknown is unworthy of consideration. We therefore can never know what we are actually missing. This leads to the question of *how much* serendipity is good for exploration, and good for the company. *How much* should we “play around” to see if there are other options? And at what point are we wasting time by going after phantoms?

Excessive serendipity leads to unstructured results, and thus to business outcomes that are not defined while the absence of serendipity in a system does not allow for unexpected findings. This is a permutation of the expectation problem: we are under the illusion that we know in which direction to search for the solution.

The analogies between biological evolution and business go even further. Moore (1996) considered business as “cooperative and competitive relationships”, strongly reminiscent of species cooperating (cooperation, symbiosis, mutualism, etc.) and concurrently competing for living space in their habitat. Let’s go on to examine how serendipity plays a part in business and oil and gas exploration in the fitness landscape of today.

5.2.1 Business Start-Ups and Incubators

A start-up is a company or project initiated to seek, effectively develop, and validate a scalable business model. In analogy to biological systems, start-ups can be seen as an embryonic or juvenile organism which still depends on external support and has potential for growth. Like in biology – not all start-ups will develop into adulthood, because they either lack resources or are ill-prepared.

Practically no start-up or new business idea has ever evolved without modification over a linear course from the inception to the final product or service that is marketable and profitable. Despite the best planning and the most favorable conditions, the path to business success is always a product of evolution (Redding, 2003) paired with good luck or serendipity in our terminology.

The process of developing business strategies is based on the inclusion of new – often untested – concepts in order to adapt to new or changing situations. As such, this process is similar to biological evolution.

Where do these new ideas come from? Start-ups, any business for that matter, like to exchange information by means of networking which is a euphemism for

8 The actual origin of this comment, an urban legend, is unknown. It is said that it was first written “in a newspaper” without mentioning an author or proper reference to the source.

socializing with business acquaintances. This may happen within the environment of co-working spaces i.e. office arrangements in which individuals of different companies work side-by-side sharing certain facilities in order to have the opportunity to informally exchange thoughts and ideas like having a chat at the coffee machine. Some writers refer to this arrangement as planned serendipity. Companies and management often attempt to engineer serendipity in business by facilitating the process through the creation of spaces like cool hangout areas or by sponsoring regular events like happy hours, speaker series, show-and-tells, workshops, hackathons, or by providing the time to gather for simply great coffee in an awesome coffee shop.

It does not require much imagination to see that this exchange of thoughts serves the same function as the exchange of DNA in biological evolution. Without fresh ideas – ideas being the DNA of business – businesses will not evolve and flourish. Moreover, such informal chats require cost and effort and are time consuming (eg. taking someone out for a business lunch), a situation that can be compared to the cost of sexual reproduction, described earlier.

Again, as in biological evolution, these human interactions do not serve the immediate purpose of message sending, receiving and understanding. On the contrary, the information exchanged during such a coffee-machine-chat can be either useful or irrelevant or simply wrong and misleading. The time wasted is analogous to unsuccessful mutations in biology. Despite these shortcomings, experience has shown that the exchange of ideas in business both within a company and between other companies is generally beneficial.

5.2.2 Mature Businesses

In mature businesses, the exchange of thoughts which serves the same function as the exchange of DNA in biological evolution comes to pass by means of company takeovers, mergers and acquisition (M&A) with other business units. When these processes, business models, methods and the “secrets of the trade” are exchanged and recombined, they are reminiscent of the recombination of DNA evolutionary biology.

An alternative model to describe the dynamics of M&A is the consumer-resource population model (Lafferty et al, 2015, – “A model for who eats and who is eaten.”) There are many types of interactions between those businesses that eat and those that are eaten which include up to three consumer activity states (questing, attacking, consuming) and up to four resource response states (susceptible, exposed, ingested, resistant). A multitude of theoretical equations describe these dynamics, from predator and prey to parasite and host. Derived from the myriad complex interactions, a simple model can accommodate any such interaction, simplifying past models into a general theory of to eat and be eaten (op.cit.).

Despite this disturbingly provocative predator-prey M&A-model, the exchange of business-DNA can and does take place at every level and like in biology, the outcome of the recombination and the fitness is not predictable with a sufficient degree of certainty. This is another example of serendipity.

5.3 Exploration for Oil and Gas

Exploration for hydrocarbons is an optimization problem: How many wells need to be drilled to discover sufficient economic resources? Truth be told: **“Exploration** (…) **is the business of being mostly wrong”** (Milkov and Navidi, 2019).

Ironically, exploration for oil and gas is a highly evolved science. Petroleum geologists, who choose locations where to test for the presence of hydrocarbons have a set of examinations and rules which they apply to map where the highest probability for the occurrence of the precious resource might be. They look at the temperatures in the ground or, to be more precise, the geothermal heat flow, along with rocks which could generate oil or gas and other rock types with good porosity, where the oil or gas can accumulate until it is found and produced.

The want-to-be oil finders apply the rules to identify the best locations. The rules and concepts applied by the petroleum geologists assume that they understand everything and can rule out certain underground situations as prospective. However, the application of their skills makes the performance of companies more predictable (less random) and reduces the impact of luck. Eventually a number of possible drilling locations, called prospects, is then submitted to a committee (usually in their respective head offices). The committees check the validity of the assumptions and conclusions and choices for the best-of-the-best prospects for drilling, – places where company money will be best invested with the expectation of profitably. However, there is confirmation bias which is the tendency to search for, interpret, favor, and recall information in a way that affirms prior beliefs or hypotheses which can lead in the wrong direction (Lee et al., 2013).

5.3.1 Lack of Serendipity

The problem lies here: The lack of factoring in serendipity. The history of petroleum exploration has many examples of areas which were – at some time – considered as not prospective but turned later into prolific oil provinces, many of which were discovered for the wrong reasons or by sheer happenstance. Serendipity is not new to petroleum exploration. Wells drilled for the only purpose to “find out”, to see what there is below the surface are called “stratigraphic tests”, drilled to understand the sequences and types of rocks present in a sedimentary basin. More recently, the practice of drilling strat wells has been rebuffed by the non-technical decision makers with the killer statement, "we are drilling for oil, not for information" (Foster, 2000, about killer phrases in exploration and how to controvert them).

Serendipity is the opposite of filtering and peer reviewing, processes that are based on the conviction that everything in the subsurface is or can be known or estimated by the geoscientist. Serendipity would be adding a component of randomness to this rigorous reviewing.

5.3.2 Quantifying Luck and Serendipity

In petroleum exploration, there is a broad consensus that "the first discoveries of petroleum in many continents, countries and basins were serendipitous" (Milkov and Navidi, op. cit). Serendipity prevailed in the early years of petroleum exploration in the USA. Pratt (1942) attributed much exploration success in the USA to entrepreneur wildcatters who drilled wells in any unexplored territory essentially randomly while disregarding opinions of expert geologists.

Not surprisingly, most companies have internal procedures to compare the outcome of exploration drilling (even in the success case called "*post mortem*") with the pre-drilling assumptions with the intention to learn from – as it often happens – failures and to quantify the amount of useful randomness or serendipity.

Mauboussin (2012) who studied sport teams, placed various activities in business, sports and investing on the continuum between luck and skill. The end-members of this continuum are winning the lottery (pure luck) and becoming a chess world champion (almost pure skill). However, most other activities have skill and luck mixed in certain proportions (ibid.).

But what is the best ratio, the best relation between luck and skill? In the example at the beginning, the little bird searching for food, will be more successful if it is equipped with a knowledge where the sought after worms and insects are most likely to occur. Likewise, exploration drilling, business, sports games will always be blessed with more success in situations where skill is paired with luck. As Latin proverb says "fortune favors the prepared" ("*fortuna eruditis favet*").

The question as to *how much serendipity* is best remains largely unanswered. Milkov and Navidi, op. cit., used the ratio (or variance) between pre-drilling expectation and post-drilling results as an indicator of the skill vs luck relationship. However, the underlying assumption, the pre-drilling expectation is already flawed because explorers erroneously tend to ignore the base rates likely because the expectations are poorly constrained and, as a result, exploration portfolios generally fail to deliver as promised (Milkov, 2017).

We conclude that for the most part it remains unclear *how much* serendipity would be optimal and beneficial for petroleum exploration in particular and business in general; it remains an elusive parameter.

6.0 Discussion and Conclusions

6.1 Consequences

As illustrated in the bird-example, the fundamental questions remain: How many variations should be tried, and *how much* serendipity is best? If the species produces only mutants, there is a risk, that none of the variants is suitable and the species may eventually become extinct. This is similar to the bird in our example that tries too many tress without feeding. Moreover, producing unsuccessful mutants comes at the cost of producing less of the normal offspring, which will survive with some degree of certainty. On the other hand, if the species does not try any new models and always produces the same, it will eventually become extinct with certainty because it can assumed with a high probability that the future will be different from the present – although we can not possibly predict in which way[9].

6.2 Summary and Conclusion

- Contrary to what intuition would suggest, serendipity is beneficial and enhancing the quality of decision making. It allows for variation and inclusion of less-likely possibilities into the basket of possible solutions.
- In exploration, a certain amount of serendipity is good for the business, good for decision-making, and good for innovation. We should dedicate some time, some resources, and some funds to matters that are clearly not directly related to the solution of usual business problems.
- The question of *how much* serendipity is actually good for business is an optimization problem, the solution of which depends on nature and objective of the enterprise. However, current knowledge suggests that there is no method or even less a mathematical solution, to quantify the optimal ratio of expectation-driven effort versus serendipity.

9 Palaeontology teaches us that certain organisms have existed without change for a long time, some nearly as long as the Earth's history. These primitive organisms have survived because they have very low requirements to their environment. As such they never have successfully conquered any ecological space – unless there was no competition for it.

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